Thermal Analysis and Optimization of Liquid Cooled Li-Ion Battery Thermal Management System

A

Synopsis

Submitted in partial fulfilment of the requirement of

Doctor of Philosophy

in

Mechanical Engineering

Submitted by

Saurav Sikarwar

Under the supervision of

Dr. Rajesh Kumar
(Co-supervisor)
Department of Mechanical Engineering
Dayalbagh Educational Institute
Dayalbagh Agra, (U.P.) -282005

Dr. Ashok Yadav
(Supervisor)
Department of Mechanical Engineering
Dayalbagh Educational Institute
Dayalbagh Agra, (U.P.) -282005

Department of Mechanical Engineering

Faculty of Engineering

Dayalbagh Educational Institute (Deemed University)

Dayalbagh, Agra-282005

2023

1. Introduction

Hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and other pollutants are produced in large quantities by conventional fuels, such as gasoline and diesel used in internal combustion engines. These are the main sources of carbon pollution that affects the ecosystem and depletes the earth's supply of fossil fuels. Because running cost of electric vehicles is less than engine-driven vehicles, researchers are switching to EVs at a faster rate. The EV is the finest alternative source of effective working without emitting a lot of carbon dioxide and with lower manufacturing and operating costs. Since lithium-ion batteries are the most efficient among all battery types from an efficiency standpoint, almost all electric vehicles use them as energy storage. However, maintaining temperatures of the battery within the range of 15°C to 35°C is a major issue [1]. The high temperature damages the battery electrodes and raises the risk of thermal runaway, which affects the vehicle's performance adversely and even cause accidents, a threat to the safety. Electron mobility in chemical reactions during the charging and discharging process can cause excessive heating, which has a negative impact on batteries and may even cause damage to them. So, a Battery Thermal Management System (BTMS) makes it possible to maintain the temperature of lithium-ion batteries in an electric car, which is of utmost importance.

Researchers have recently focused on the most effective thermal management of batteries. Understanding the link between material, fluid velocity, contact area to coolant, and other parameters is crucial to improve BTMS performance. Therefore, identifying key processes, parameters, and the ideal battery pack temperature will improve BTMS quality. The current lithium-ion (Li-ion) batteries have been widely used in electric vehicles (EVs) and are regarded as the most suitable energy storage device for electric-driven vehicles due to their large specific energy, high specific power, low self-discharge rate, high voltage, relatively long life, and good recyclability. The performance of Li-ion batteries will be impacted by storage temperature as well as operating temperature. According to studies, temperature has a major impact on battery ageing and negatively affects internal resistance and capacity. The thermal performance of batteries is negatively impacted by temperatures above the recommended range, which significantly reduces battery lifetime and capacity. According to the estimates, the battery lifespan decreases by two months for every degree rise in temperature [2]. At the

same time, it is advised that a battery pack's internal temperature differential should not rise above 5℃. To keep battery temperatures within the appropriate range and to minimise temperature non-uniformity within the battery pack, effective battery thermal management systems (BTMS) must be designed [3].

The relationship between all the parameters and the various BTMS types, particularly the various types of material utilised for cooling in BTMS, hasn't been well researched. The numerous types of BTMS and the improvements that may be made to them are the focus of the current research trend, which will be explored in both ways experimentally and through modelling. This research is important since electric vehicles are quickly replacing traditional technology and are increasingly being adopted in large-scale production owing to improvements. With the aid of BTMS, research will be conducted to determine the ideal temperature of an electric vehicle's Li-ion battery pack. For electric vehicles and other industrial applications, phase change material (PCM), based air-based and liquid-based, BTMS are most frequently employed [4].

2. Types of Battery Thermal Management Systems

There are mainly four types of BTMSs used for cooling the battery pack.

1. Air-based BTMS
2. Liquid-based BTMS
3. PCM-based BTMS
4. Hybrid Type BTMS

Significant research has been put towards creating new BTMSs and improving those that already exist lately. The BTMS would require even more attention given the present trend toward higher charging rates, which would enable faster charging and longer travels [2].

3. Literature Review

Battery thermal management is an essential part of Battery pack to maintain the temperature in the optimum range. A lot of work is being carried out in this area to find an optimum and efficient BTMS. BTMS’s can mainly be categories on the basis of cooling medium that can be Air, water or PCM based on the requirement of cooling and availability. Further analysis can be done in both ways simulation and experimental. Based on the types of different BTMS, a critical literature review is

carried out in this section [5].

3.1. Air-based BTMS

The air-cooling BTMS has been widely used in EVs and HEVs industry with cost-reduction demand or under severe and unpredictable working environments. The basic air-cooling BTMS design is reviewed here, and a variety of novel design improvements was evaluated to explore the benefits and challenges of the use of the air-cooling BTMS [6, 7].

Xinxi Li et al. (2018), worked on, lithium-ion polymer battery pack taken to maintain the optimum temperature range. To control the battery pack thermally at the different location, where the different velocity of air passed over the battery pack with number of silica cooling plate & fans finally optimal choice for cooling the battery pack (5C discharge rate) 1.5 mm silica cooling plate, air velocity of 3.5 m/s & two fans.

Leone Martellucci et al. (2021), the primary goal of research project was to use an air medium to keep the battery pack at its optimal temperature. The 18650 Li-ion cell battery pack with variable airflow, cell spacing, and configuration that operates at 1.5C and 3C rates of current was used to test. The maximum temperature was 23.7°C and the difference was 2.5°C at 1.5 C rate, 1.5 mm spacing, and air velocity. The maximum temperature at 3 C rate, 1.5 mm spacing, and 11 m/s air velocity was 32.45°C, with a 6.2°C differential. Higher velocity and other spacing of 2 mm and 2.5 mm produced better results but required more power.

Patcharin Saechan et al. (2022), worked to figure out the optimal temperature range for 18650 Lithium-ion battery pack, by considering number of configurations (cells), air flow rate, and air velocity as variables. They conclude the 17.4% less temperature as compared to no air velocity flow on the aforesaid arrangement with an Inlet air velocity of 5 m/s, Inlet air temperature of constant, Battery arrangement of 3×8 rectangular, and Discharge rate of 3C.

It was found that with the help of advanced computational numerical simulations and sophisticated experiments, the air-cooling efficiency was greatly improved by introducing new concepts of battery packs, innovative designs of the cooling channel, and novel thermally conductive materials. Based on the review, this paper suggests future research directions and potential solutions in a discussion for further development of the air-cooling BTMS in the EV and HEV industry.

3.2. Liquid-based BTMS

BTMS are generally divided into active and passive cooling methods. Air cooling based BTMS are simpler in design and operation and consume relatively less power than liquid cooling-based systems, but their heat-dissipating capacity is very small due to the lower specific heat capacity of air. Despite having a more complicated design and higher power consumption, liquid-based cooling is the most popular choice due to its superior heat dissipation and higher specific heat capacity of the liquid. Therefore, various EVs like Tesla Model S, BMW i5, BMW i3, Audi Q7, and Chevrolet Volt have extensively employed liquid-based BTMS [8, 9].

Jiaqiang E et al. (2017) applied, design of experiments and selected an orthogonal array $L_{16}(44)$, which provides quantified parametric to identify the primary and secondary criteria for finding the best combination for keeping the temperature in desired range of the battery pack. Results of the study indicated that the channel height, width, and number of channels have a direct impact on the rate of heat dissipation, while the coolant flow, quantity, and quality are also significant factors in the heat dissipation of battery packs. The results, demonstrated that, when the channel width was 45 mm, channel height was 5 mm, the channel number was 4, and the cooling liquid flow rate was 0.07 m/s, the battery pack experienced a good cooling as compared to other combinations of parameters.

Rao et al. (2017) analysed, a unique liquid cooling BTMS design and compared the thermal performance for a lithium-ion battery pack. The maximum temperature and temperature difference was monitored with a constant surface L. first taken in the cooling system, the simulation used for a battery pack of six cells with flow channels was investigated to check the influence of aluminium block length and velocity on the thermal performance of BTMS. They found that when L & velocity increases, the maximum temperature and temperature differential decrease. The battery pack can be kept cool to a maximum temperature of under 40°C when the valve of L is 24 mm and the coolant is moving at a velocity of 0.05 m/s. A changing contact surface was suggested instead of a constant surface to further enhance the temperature dispersion in the battery pack. When K = 3 mm and velocity was less than 0.1 m/s, the temperature distribution was evaluated for various slopes with K = 1 mm, K = 2 mm, and K = 3 mm; this combination produced the most uniform temperature in the battery pack. When the weight and power requirements of the pump, was considered a system with a

changeable contact surface is considerably superior to one with a constant surface. When the inflow velocity was 0.05 m/s for L = 24 mm, the maximum temperature drop as well as the temperature differential for the same valve, were reduced by 6%, 14%, and 28%, respectively, while the system weight was decreased by 20%, 29%, and 47%. In their research work the valve with K = 3 mm was main valve for the given system three combination of the design were taken for three slops.

Shang et al. (2018) analysed a liquid cooled BTMS of li-ion battery through simulation and experimentation. Their work was to select the optimal parameters for the liquid cooling-based BTMS. The simulation was run with the numerical data that was used to formulate the experimental setup numerically. Again, experiments confirmed the simulation's accuracy level. The outcome reveals that the breadth of cooling plate reduction. was varied from 55 to 75 mm, and for this range there were maximum temperature decreases. The input temperature was also changed from 24℃ to 15℃. It was highly challenging to improve battery performance with a single parameter change, even though several factors affected the thermal performance of the battery pack. The optimal temperature difference was achieved in the range of 15 ℃ to 24 ℃, the mass flow rate of 0.17 kg/s to 0.25 kg/s, and the width of the cooling plate is 60 mm. The lowest value of maximum temperature was reached with the following conditions: inlet temperature of 18℃, mass flow rate of 0.21 kg/s, and cooling plate width of 70 mm.

3.3. PCM-based BTMS:

PCM has a high latent heat due to this it plays an important role as a heat sink during battery pack discharge and absorbs additional heat that is not helpful for the battery pack. When the battery pack is in standby. However, PCM releases heat to the battery pack and the area around the system. PCM-type BTMSs are most produced to work within a Li-Ion battery pack's higher temperature range [10, 11].

Amin et al. (2018) found during the operation of EV, the temperature of battery rose significantly. Especially when it was first charged, and this could be a sign of a thermal runaway. Electric vehicle's performance is closely correlated with its battery health. The heat pipe with phase change material (PCM) was suggested to keep the temperature of the battery pack within a certain range. When the battery was in operation, heat was transported from the battery pack to the PCM by a heat pipe, to maintain constant temperature and extending the battery pack's lifespan. With the use of a combined

solution heat pipe and PCM, it was claimed to improve the performance of electric vehicle batteries at a temperature of 50℃. Beeswax PCM and L-type heat pipes were employed as the cooling arrangement, while simulator test equipment adjusted the heating load from 20 W to 50 W with respect to intervals of 10 W. A combination of heat pipe and PCM was suggested as a solution for battery cooling in the heat load range of 20 W to 50 W, successfully lowering battery temperature down below 50℃.

Raju et al. (2021) as internal combustion engine needs a specific temperature range to function effectively, the electric car also needs a optimum temperature range. Although, the researchers employed numerous techniques, the phase change material is the latest one for BTMS cooling. As a result of the PCM's high latent heat capacity, the battery also absorbs a significant quantity of heat. PCM properties were utilized to cool the battery pack. Through simulation (ANSYS Fluent), a multidimensional 3D battery model was simulated to determine the temperatures. necessary to solidify and melt a PCM after heating the battery cells. They examined several C-rates to determine how long it took a battery to discharge as well as the effects of various C rates on PCM performance. Although the battery temperature. with and without the PCM was recorded, the temperature difference between the two was ultimately compared.

E Grimonia et al. (2021), analysed the performance of 18650 cylindrical lithium-ion battery pack with varied PCM material thicknesses to reach the optimum temperature range. The main factors include material, thickness; time, PCM phase change, and different battery pack C rates. At last, PCM Hexacosane, which is 9 mm thick, lowers the temperature by 6.54°K, but PCM Capric Acid, which is 9 mm thick, lowers the temperature by only 2.84°K comparatively. Furthermore, the best solution is PCM Hexacosane with a 9 mm thickness.

3.4. Hybrid Type BTMS

In a hybrid system, two or more mediums are used. The most frequent hybrid systems that can be studied for improved cooling are those that combine PCM materials with either an air-based or liquid-based system. A useful alternative for cooling a battery pack is a heat pipe [12, 13].

Belyaev et al. (2014) concluded that although battery span life and thermal performance have a small range, the lithium-ion battery pack is employed in practically all electric vehicles. In their work two

battery simulations with the heat pipe was cooled by airflow of 3 l/s, and this system temperature ranged from 9℃ to 40℃. The information gathered through computer modelling procedures to determine the heat pipe's actual thermal conductivity and its thermal state with respect to surface temperature distribution. According to the simulation results, the radiator's ribs, which were cooled by air, exhibit the largest thermal resistance transition. The more effective heat pipe radiators were required for the additional cooling.

Moghaddam (2019) explained that due to great energy density, lithium-ion batteries are crucial in the storage industry. The most popular battery thermal management techniques, including direct and indirect liquid cooling, air cooling, phase change materials (PCM), computational fluid dynamics (CFD) simulation was used to demonstrate the performance of four distinct BTMSs. Battery temperature distribution, battery module temperature, and battery power consumption were compared through simulation findings. Air cooling methods, liquid cooling techniques had a superior cooling performance since the battery was in direct contact with the liquid through channels and pipelines.

Behi et al. (2020) suggested that three types of cooling techniques can be used for the thermal control of lithium-titanate (LTO) batteries. The cell's temperature was 22 ℃ with natural air cooling at the 8C discharged rate. Other cooling methods including liquid cooling and flat heat pipe cooling were also tested. Single heat pipe required only 29.1% cooling load while discharged rate 8C. Thermal conductivity is another crucial factor that can be calculated for flat heat pipe technologies. 15 cells were connected in series with liquid cooling in the optimization model, and LCHP was simulated. The experimental results and the numerical simulation were well validated. Finally, it was concluded that as compared to natural air cooling, Liquid cooling system and LCHP was given the reduced temperature by 29.9% and 32.6% respectively.

4. Formulation

Huanwei Xu et al. (2021), to find the coolant flow with the help of the Reynolds number (Re), the relations are as follows:-

$$Re = \rho v d/\mu \tag{1}$$

where,

v = velocity of fluid

ρ = density of fluid

μ = viscosity coefficient of fluid

d = characteristic length

The cooling channel absorbs the heat directly from the battery pack through direct contact of battery cells due to the coolant flow inside the cooling channels. Although, the heat is transferred by thermal conduction from the battery pack to the cooling channels, the energy conservation equation for battery pack is as follows:

$$\rho C \partial T/\partial t = k(\partial^2 T/\partial x^2 + \partial^2 T/\partial y^2 + \partial^2 T/\partial z^2) + Q \quad (2)$$

where,

ρ = density of the battery

C = heat capacity of the battery

T = temperature of the battery

t = time

k = thermal conductivity

Q = heat generation rate in battery

The energy conservation equation of the cooling channel is as follows:

$$\rho_p C_p \partial T_p /\partial t = \nabla(k_p \nabla T_p) \quad (3)$$

where,

ρ_p = density of the cooling channel

C_p = heat capacity of the cooling channel

T_p = temperature of the cooling channel

k_p = thermal conductivity of cooling channel

The convective heat transfer equation used for the outer surface of the battery and air form a convective boundary condition is as follows:

$$q = h (T - T_0) \quad (4)$$

where,

q = heat production rate per unit volume

h = the convective heat transfer coefficient

T_0 = the ambient temperature

The energy conservation equation of water (coolant) is as follows:

$$\rho_c C_c \partial T_c / \partial t + \nabla(\rho_c C_c v Tc) = \nabla(k_c \nabla T_c) \quad (5)$$

where,

ρ_c = the mass density of the coolant

C_c = heat capacity of the coolant

T_c = temperature of the coolant

k_c = thermal conductivity of the coolant

v = velocity of the coolant

The continuity equation is as follows:

$$\partial \rho_c / \partial t + \nabla(\rho_c v) = 0 \quad (6)$$

Let the fluid is incompressible and the density does not change with time then the equation are

$$\nabla (v) = 0 \quad (7)$$

The momentum equation of the coolant (water) is:

$$\rho_c dv / dt = -\nabla P + \mu \nabla^2 v \quad (8)$$

where,

P = the static pressure of the coolant

μ = dynamic viscosity of the coolant

5. Objectives of Proposed Work

The proposed work is focused to keep the Li-ion battery pack's temperature within the optimal range to improve performance using battery thermal management.

The proposed objectives for this research are as follows.

1. Influence of various compositions of coolant in liquid cooled BTMS with varying flow rate.

2. Effects of configuration of cooling tubes used in liquid BTMS.

3. Thermal analysis of battery cooling using thermocouples and data logger.

4. Optimization of battery thermal management system using RSM.

5. Mathematical modelling of BTMS using MATLAB-Simulink module.

6. Experimental Setup

This objective of the research work is to determine the optimal temperature range for lithium-ion battery packs. To achieve this goal, various copper-based cooling channels, such as U-shaped cooling channels, half-wave cooling channels, and serpentine cooling channels, will be tested. Experimentally, we will figure out the optimal result for the BTMS's optimum temperature range.

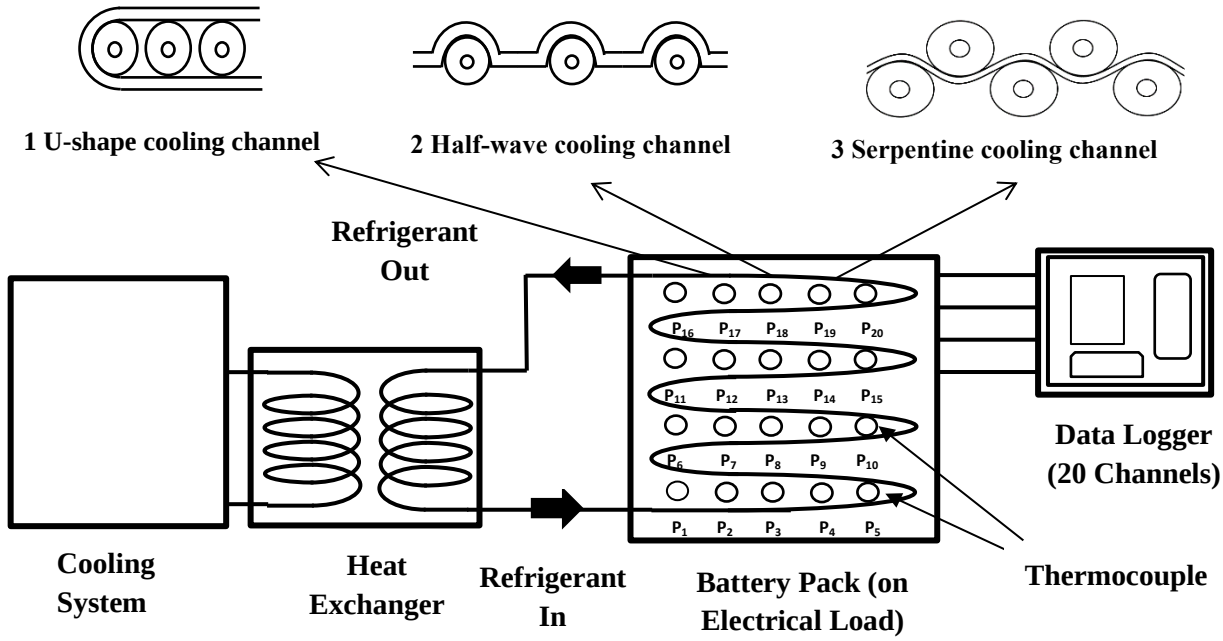

Fig. 1 Lithium-Ion Battery Thermal Management System

7. Procedure

The purpose of our study is to use liquid cooling to maintain the temperature range of lithium-ion battery pack. Water, water with glycol, and water with glycol plus added nanoparticle mixture will be used as coolants. If the experimental temperature data is lower than expected, then the battery pack can be kept cold with just water (for less rate battery pack). According to experimental data, if the temperature rises higher, water will not be sufficient to cool the battery pack; in this situation, we will employ water containing a glycol solution as well as nanoparticles. All coolant will be circulated at

varying flow rates. Consequently, we will make use of the various cooling channels (U-shape cooling channel, half wave cooling channel, and serpentine cooling channel) as shown in figure 1 which provide different efficiency rates. A comparative analysis will be done for all the cooling channels. A heat exchanger that is directly connected to the cooling system helps coolant flow inside the channel as it absorbs heat from the battery pack. Thermocouple will be used to measures the temperature in various locations, above the battery pack. The device also includes a data logger that records temperature data at regular intervals and displays it.

I. PARAMETERS

Experimentation will be carried out using the parameters given below.

- Configuration of cooling channels (To vary contact area)
- Composition of coolant (To vary properties of coolant)
- Flow rate

PARAMETERS & THEIR LEVELS:

Different compositions of coolant at different levels will be used in U-shape, half wave and Serpentine type of cooling channels as depicted in Table 1.

Table 1: experimentation plan with input parameters

Sr. No	Cooling Channel Types	Composition of Coolant					Flow Rate (LPM)
		Level 1	Level 2	Level 3			
1	U- shape	Water	Water + glycol (equal amount)	Water + glycol (equal amount) with			1,2 & 3 in all levels
				5% nanoparticles	10% nanoparticles	15% nanoparticles	
2	Half-wave	Water	Water + glycol (equal amount)	Water + glycol (equal amount) with			1,2 & 3 in all levels
				5% nanoparticles	10% nanoparticles	15% nanoparticles	
3	Serpentine	Water	Water + glycol (equal amount)	Water + glycol (equal amount) with			1,2 & 3 in all levels
				5% nanoparticles	10% nanoparticles	15% nanoparticles	

II. OUTPUT

Output of the above experimentation are given below which will be used for further analysis.

a. Average cell Temperature and temperature difference

b. Rate of heat transfer

References

1. Z. Rao and S. Wang, “A review of power battery thermal energy management,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4554–4571, 2011.
2. S. S. Katoch and M. Eswaramoorthy, “A Detailed Review on Electric Vehicles Battery Thermal Management System,” in *IOP Conference Series: Materials Science and Engineering*, Sep. 2020, vol. 912, no. 4.
3. Z. Wan, J. Deng, B. Li, Y. Xu, X. Wang, and Y. Tang, “Thermal performance of a miniature loop heat pipe using water-copper nanofluid,” *Appl. Therm. Eng.*, vol. 78, pp. 712–719, 2015.
4. R. Zhao, S. Zhang, J. Liu, and J. Gu, “A review of thermal performance improving methods of lithium ion battery: Electrode modification and thermal management system,” *J. Power Sources*, vol. 299, pp. 557–577, 2015.
5. M. Al-Zareer, I. Dincer, and M. A. Rosen, “A review of novel thermal management systems for batteries,” *International Journal of Energy Research*, vol. 42, no. 10. John Wiley and Sons Ltd, pp. 3182–3205, Aug. 01, 2018.
6. P. Ramadass, B. Haran, R. White, and B. N. Popov, “Capacity fade of Sony 18650 cells cycled at elevated temperatures: Part I. Cycling performance,” *J. Power Sources*, vol. 112, no. 2, pp. 606–613, 2002.
7. I. Uchida, H. Ishikawa, M. Mohamedi, and M. Umeda, “AC-impedance measurements during thermal runaway process in several lithium/polymer batteries,” *J. Power Sources*, vol. 119–121, pp. 821–825, 2003.
8. A. Jossen, V. Späth, H. Döring, and J. Garche, “Reliable battery operation - a challenge for the battery management system,” *J. Power Sources*, vol. 84, no. 2, pp. 283–286, 1999.
9. S. Yang, C. Ling, Y. Fan, Y. Yang, X. Tan, and H. Dong, “A review of lithium-ion battery thermal management system strategies and the evaluate criteria,” *International Journal of Electrochemical Science*, vol. 14, no. 7. Electrochemical Science Group, pp. 6077–6107, 2019.
10. T. Wang, K. J. Tseng, J. Zhao, and Z. Wei, “Thermal investigation of lithium-ion battery module with different cell arrangement structures and forced air-cooling strategies,” *Appl. Energy*, vol. 134, pp. 229–238, 2014.

11. L. H. Saw, Y. Ye, and A. A. O. Tay, “Electrochemical-thermal analysis of 18650 Lithium Iron Phosphate cell,” *Energy Convers. Manag.*, vol. 75, pp. 162–174, 2013.
12. L. H. Saw, Y. Ye, A. A. O. Tay, W. T. Chong, S. H. Kuan, and M. C. Yew, “Computational fluid dynamic and thermal analysis of Lithium-ion battery pack with air cooling,” *Appl. Energy*, vol. 177, pp. 783–792, 2016.
13. T. I. C. Buidin and F. Mariasiu, “Battery thermal management systems: Current status and design approach of cooling technologies,” *Energies*, vol. 14, no. 16, 2021.
14. B. Ye, M. R. H. Rubel, and H. Li, “Design and optimization of cooling plate for battery module of an electric vehicle,” *Appl. Sci.*, vol. 9, no. 4, 2019.
15. K. Monika, C. Chakraborty, S. Roy, S. Dinda, S. A. Singh, and S. P. Datta, “An improved mini-channel based liquid cooling strategy of prismatic LiFePO4 batteries for electric or hybrid vehicles,” *J. Energy Storage*, vol. 35, no. December 2020, p. 102301, 2021.
16. M. Shen and Q. Gao, “Structure design and effect analysis on refrigerant cooling enhancement of battery thermal management system for electric vehicles,” *J. Energy Storage*, vol. 32, no. May, p. 101940, 2020.
17. Y. Zhang, J. Huang, M. Cao, G. Du, Z. Liu, and W. Li, “Preparation of boron nitride and silicone rubber composite material for application in lithium batteries,” *Energies*, vol. 14, no. 4, 2021.
18. P. Dubey, G. Pulugundla, and A. K. Srouji, “Direct comparison of immersion and cold-plate based cooling for automotive li-ion battery modules,” *Energies*, vol. 14, no. 5, 2021.
19. E. Jiaqiang *et al.*, “Orthogonal experimental design of liquid-cooling structure on the cooling effect of a liquid-cooled battery thermal management system,” *Appl. Therm. Eng.*, vol. 132, pp. 508–520, 2018.
20. S. Mazyar and H. Moghaddam, “Designing battery thermal management systems (BTMS) for cylindrical Lithium-ion battery modules using CFD.”
21. P. Saechan and I. Dhuchakallaya, “Numerical study on the air-cooled thermal management of Lithium-ion battery pack for electrical vehicles,” Energy Reports, vol. 8, pp. 1264–1270, 2022.
22. L. Martellucci and K. K. Krishna, “Analysis of Air-Cooling Battery Thermal Management System for Formula Student Car,” J. Transp. Technol., vol. 11, no. 03, pp. 436–454, 2021.

23. X. Li, F. He, G. Zhang, Q. Huang, and D. Zhou, “Experiment and simulation for pouch battery with silica cooling plates and copper mesh based air cooling thermal management system,” Appl. Therm. Eng., vol. 146, no. October 2018, pp. 866–880, 2019.
24. E. Grimonia, M. R. C. Andhika, M. F. N. Aulady, R. V. C. Rubi, and N. L. Hamidah, “Thermal Management System Using Phase Change Material for Lithium-ion Battery,” J. Phys. Conf. Ser., vol. 2117, no. 1, 2021.
25. H. Behi et al., “Thermal management analysis using heat pipe in the high current discharging of lithium-ion battery in electric vehicles,” J. Energy Storage, vol. 32, no. April, p. 101893, 2020.
26. Huanwei Xu et al., “Optimization of liquid cooling and heat dissipation system of lithium-ion battery packs of automobile” Published by Elsevier Ltd.
27. https://e-amrit.niti.gov.in/ visited on 1 November 2022 at 4:00 pm
28. https://batteryuniversity.com/ visited on 5 November 2022 at 1:00 pm